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Review

Cross-Docking: A Systematic Literature Review

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Abstract: This paper identifies the major research concepts, techniques, and models covered in the cross-docking literature. A systematic literature review is conducted using the BibExcel bibliometric analysis and Gephi network analysis tools. A research focus parallelship network (RFPN) analysis and keyword co-occurrence network (KCON) analysis are used to identify the primary research themes. The RFPN results suggest that vehicle routing, inventory control, scheduling, warehousing, and distribution are most studied. Of the optimization and simulation techniques applied in cross-docking, linear and integer programming has received much attention. The paper informs researchers interested in investigating cross-docking through an integrated perspective of the research gaps in this domain. This paper systematically reviews the literature on cross-docking, identifies the major research areas, and provides a survey of the techniques and models adopted by researchers in the areas related to cross-docking.

Keywords: cross-docking; systematic literature review; co-occurrence analysis; logistics; Gephi

1. Introduction

To date, there has been a flurry of research effort on understanding logistics and supply chain management and their various sub-domains, in particular, research techniques, modelling and frameworks, and the theoretical lenses used for extracting insights from the physical phenomena. However, not all sub-domains have been well studied and assessed in relation to their research value and opportunities, notably those aspects which are critical to the core of logistics operations. Cross-docking, a technique popularized in the 1990s, is one of them.

1.1. Cross-Docking

The activity of cross-docking is the logistics process of transshipping inventory in a flow-centre by unloading the shipments from the inbound trucks directly to the outbound trucks to reduce shipment time and cost [1,2] by eliminating storage and order picking activities, thus accelerating the flow of the shipping cycle [1]. The Material Handling Industry of America defines cross-docking as “the process of moving merchandise from the receiving dock to shipping [dock] for shipping without placing it first into storage locations” [2]. Industries implement a cross-docking strategy to improve the “just-in-time” deliveries within their supply chain in order to minimize the number of inbound and outbound trucks and enhance sustainability [3]. A cross-docking station is a site where inventory is unloaded, consolidated, and then directly reloaded onto outgoing trucks [4]. Under a cross-docking

strategy, the inventory is stored only for a short time before being reloaded onto outgoing trucks; the inventory does not stay beyond 24 hours within the cross-dock station [1,5].

In addition to cross-docking, there are other distribution strategies that are commonly used to distribute products from suppliers to customers, such as direct shipment [6,7], milk-runs [6,8], and warehousing [6]. A direct shipment strategy is based on sending shipments directly from the source to the destination [6] where trucks can perform single or multiple pick-ups and deliveries [7]. In a milk-run strategy, shipments are distributed into routes where trucks visit multiple origins and destinations sequentially [2,8]. Both direct shipment and milk-run strategies do not involve intermediary logistics facilities; hence, there are lower implementation costs. However, these two strategies are not efficient in the case of small shipment sizes and when customers are located in remote geographic areas as these will lead to longer transportation times with partially empty trucks [6]. In a warehousing strategy, trucks are loaded with products from suppliers; then, these are sent to a warehouse or distribution centre for unloading and storing. After that, the products are retrieved, assembled, and shipped upon customer order [2,6]. However, a warehousing strategy applies storage and material handling costs [6,9,10] in addition to the possibility of having partially empty trucks or the added cost of assembling loads from storage [6]. Urzúa-Morales et al. (2020) developed an optimization model to choose the physical location of the cross-docking centres to improve the design of the urban logistics system and enhance the efficiency of the distribution process and minimize its negative environmental impacts [11].

1.2. Advantages and Applications of Cross-Docking

The distribution process accounts for 30% of the product sale cost, and this aspect increases overheads of the overall supply chain process [12] and impacts negatively on the suppliers and manufacturing process due to high competition and ease of reach to several markets [13]. Consequently, there is a need to reduce the distribution costs and increase distribution efficiency [14]. A robust cross-docking strategy can overcome the high costs of storing and handling [9] through consolidating shipments from various origins and then sending the goods to a cross-dock location where the shipments are unloaded and immediately recombined with loads sharing the same destination [4,10]. Cross-docking can increase efficiency on the usage of truck capacity and full truckloads [10] by consolidating different-sized shipments bound for the same destination [7,15].

A cross-docking strategy has other advantages such as reducing the costs of warehousing, inventory-holding, handling, labour, and transportation [2], reducing delivery lead time from suppliers to customers [5,16], reducing storage space, reducing risks of product damage and obsolescence, consolidation of shipment, improving resource utilization, reducing overstock [2], providing more control over delivery schedules [8], improving service level [9,16], and lifting the rate of inventory flow and sales turnover [5]. Thus, it is a popular firm-level strategy [15].

There are several reported applications of cross-docking in the literature. For instance, in the food industry, cross-docking of food distribution provides better efficiencies as well as significant cost savings [17]. There are other successful implementations of cross-docking in retail such as Walmart [2] and Office Depot [1,18], besides those of Toyota, Goodyear, Eastman Kodak, Dots, and LLC [2]. Wal-Mart was the first firm to propose this strategy and they improved their profit and increased market share [5]. In 1992, Wal-Mart was the most profitable retailer globally due to applying cross-docking on 85% of its inventory, which also contributed to a 2–3% cost saving [1]. The cross-docking approach is also practised in the pharmaceutical supply chain to manage speed to market and pharma waste through better scheduling and improving medication room response time and eliminating unnecessary activities [19]. Khorasani et al. (2018) reported that cross-docking is efficient for moving numerous items within short periods of time [19]. Cattani, Souza and Ye (2014) suggested applying a cross-docking system at the fulfilment centres for online retailing to reduce the delivery times as well as the shelving and handling expenses, and shipment costs in some cases [20].

1.3. Literature and Studies on Cross-Docking

Research studies in this field applied several models in cross-docking aiming to solve different problems and improve cross-docking operations. These studies include scheduling, dock door assignment, transshipment, vehicle routing, product allocation, and layout design and network.

Studies have investigated the vehicle routing problem to increase the efficiency of decision making at the operational level and to improve the tactical transportation plan [21]. These studies followed different approaches such as developing a model for the vehicle routing problem by considering the pickup and delivery routes for product transportation (Maknoon and Laporte, 2017); and investigating the product mix allocation problem [22].

Scheduling problems in cross-docking have been well investigated by several studies. Many aspects of the class of scheduling problems were considered in previous studies including proposing a model to solve the truck scheduling problem in a multi-door cross-docking system [16]; investigating Just-in-Time (JIT) scheduling with time windows penalties to minimize the storage time [23]; developing a model for efficient scheduling of the inbound trucks to arrive on time and for outbound trucks to depart on time [24]; and, developing a scheduling model for inbound and outbound trucks to minimise the travel distance [25]. Truck scheduling problems in the cross-docking centres have been investigated to identify the potential for improving the operations of cross-docks [26]. On the sustainability of supply chains, Chargui et al. (2019) optimized the Rail–Road Physical Internet-Hub cross-docking terminal operations by scheduling the outbound trucks at the docks [27]. Furthermore, studies in this area have investigated problems related to the scheduling of transshipment operation in a multiple inbound and outbound dock configuration to minimise the total cost of inventory holding and truck replacement [28], the parcel hub scheduling problem to minimize the time of transfer operations [29], and studied the inbound and outbound truck sequencing to minimize the total turnaround time [30].

More studies have emerged in the field of cross-docking. There are studies utilizing mathematical models to solve problems such as developing a model that schedules the inbound trucks without affecting the outbound trucks' schedule to solve the problem of the randomly arriving trucks exceeding the number of outbound trucks [31]; a model for assigning and clustering the destinations to the shipping doors of the mail distribution centre to increase the efficiency of the sortation centre [32]; a model to economise decision making regarding the cross-docking location selection problem [33]; designing a cross-docking layout model to determine the temporary storage location for incoming unit loads through minimizing the travel distance of the forklift trucks with unit loads [34]; and developing two models to determine a production-distribution strategy to reduce the total cost percentage and to help in selecting the best approach of distribution for a manufacturer's production process [35].

Furthermore, other studies investigated the assignment problems for fully loaded incoming trucks to reduce the total handling cost [36], developed an approach for assigning destinations to dock doors to minimize the number of workers in the loading operations [37], and compared three cross-docking designs using a genetic algorithm to increase the efficiency in the logistics distribution network [38].

1.4. Literature Gap

Upon reviewing the cross-docking models, review studies have focused on the cross-docking operations perspective, i.e., the truck scheduling problem at the cross-docking terminals [26], investigated and compared the practices between industry and academic studies by identifying the cross-docking operations in the literature and industry practice [1], reviewing models on cross-docking terminal planning [39], reviewing characteristics and problem types related to cross-docking [2], and scheduling problems [15].

More than 85% of the academic papers on cross-docking are published post-2004 [40]. In addition, only a few studies have considered the integration of different models to solve problems related to cross-docking [12] and these studies focused on applying models to cross-docking operations [41]. Therefore, this paper aims to identify the recent trends in the cross-docking literature by presenting a comprehensive review of the cross-docking models and applications.

1.5. Research Statement and Objectives

The study reviews the extant research on cross-docking models and identifies the gaps in the knowledge of cross-docking models and informs the future research directions in cross-docking. This paper addresses the research gap by analysing and identifying the research foci on cross-docking. The objective of this review is thus to identify the (1) major research areas of cross-docking, (2) techniques and models, and (3) opportunities for future research on cross-docking.

The rest of this paper is set as follows: Section 2 proposes the method of reviewing the literature. Section 3 presents the results and discussion. Section 4 concludes the paper.

2. Review Method

From the research objectives, the research questions have been framed to determine the approaches for use in this review. The research questions are, namely, (1) What are the major research areas that have been covered in the area of cross-docking? (2) What are the techniques and models that have been researched on cross-docking? and (3) What are future research areas in cross-docking?

The approach followed in this paper to review the literature is depicted in Figure 1.

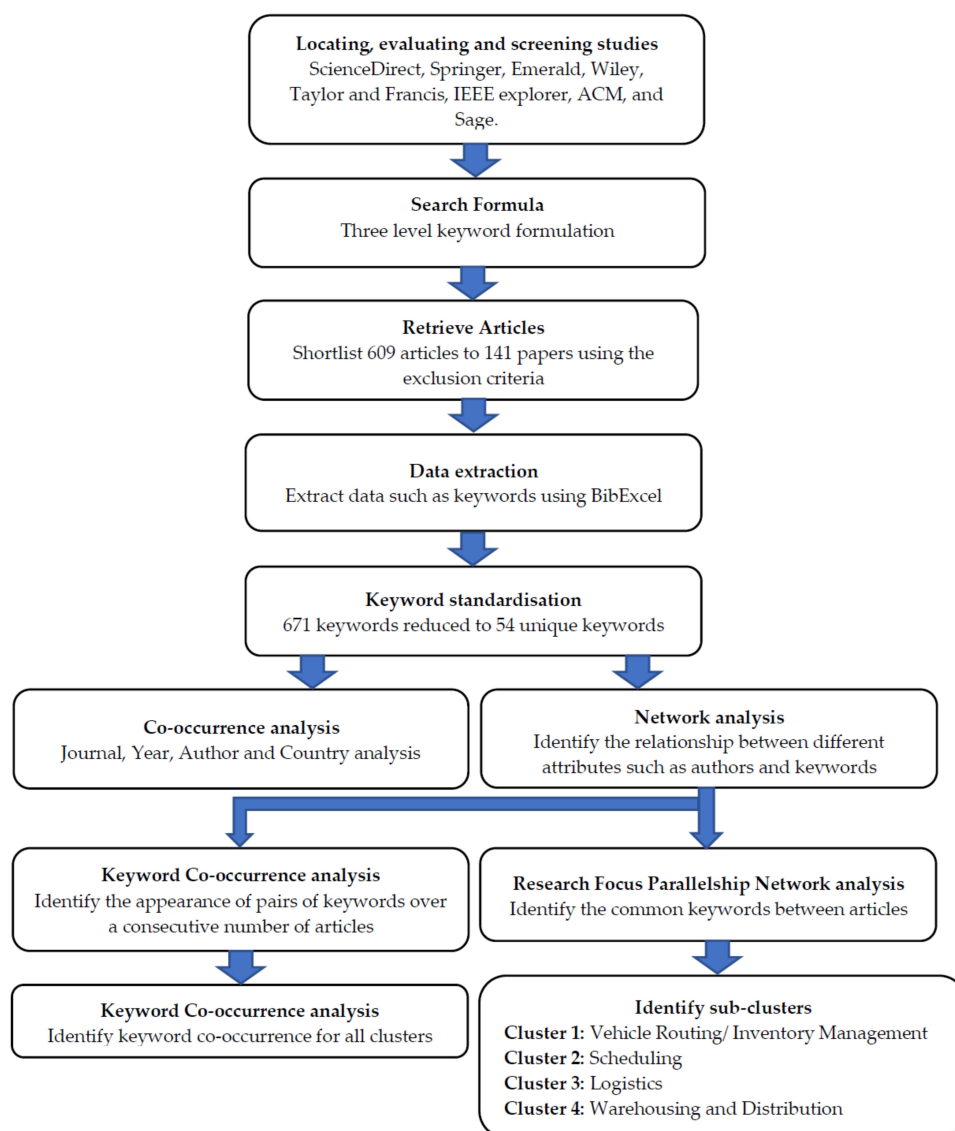


Figure 1. Methodological framework of the review.

To achieve the research objectives and questions, we conducted both the research focus parallelship network (RFPN) analysis and the keyword co-occurrence analysis. This review proposes two phases for selecting and analysing the research papers.

2.1. Phase I: Locating, Evaluating and Screening Studies

The papers selected for review were identified and searched from the following well-known academic databases in which most of the cross-docking and supply chain journals publish, namely ScienceDirect, Springer, Emerald, Wiley, Taylor and Francis, IEEE explorer, ACM, and Sage.

Table 1 shows the keyword search formulation criteria used. The structure defines popular keywords to obtain a broader range of studies. Accordingly, Level 1 defines the search context “cross-docking,” Level 2 used the keyword “supply chain”, and level 3 outlines the keyword “logistics.” The publishing dates were limited to papers published by 30 October 2018, with no restrictions on the start date of publishing.

Table 1. Search criteria.

Keyword Formulation	
Level 1	Crossdock* OR Cross-dock* OR Cross dock* OR
Level 2	Supply chain and Crossdock* OR Supply chain and Cross-dock* OR Supply chain and Cross dock*
Level 3	Logistics and Crossdock* OR Logistics and Cross-dock* OR Logistics and Cross dock*

To achieve the research objectives and questions, we conducted both the RFPN analysis and keyword co-occurrence analysis. This review proposes two phases for selecting and analysing the research papers, as follows.

A total of 609 articles were identified, and exclusion criteria were used to shortlist and screen the papers. The following papers were excluded: open access papers, editorial notes, and conference papers including Procedia and IFAC (The International Federation of Automatic Control). As a result, 141 papers were shortlisted for this study, over a time-window of 21 years, from 1997 to 2018 inclusive.

2.2. Phase II: Data Extraction and Co-Occurrence Analysis

We extracted the data for bibliometric analysis using the bibliometric tool BibExcel. BibExcel, developed by Persson [42,43] facilitates data management and analysis [44]. BibExcel generates data files [43] from large amounts of data and provides a statistical analysis [45], and imports the data from research databases such as Web of Science and Scopus in formats compatible with other software such as SPSS and Excel [44], and network analysis tools such as Pajek and Gephi [45].

The data is entered into Bibexcel in the RIS format, with information on the title, authors, journal, publication year, and keywords. The keywords were retrieved, reviewed, and standardized because many keywords described the same meaning but were worded differently.

Next, the following analyses are performed using Bibexcel:

1. Journal analysis to identify the distribution of the articles in the journals;
2. Year analysis to identify the distribution of articles throughout this period;
3. Country analysis to identify the contributing countries in this field.

Thereafter, a semantic network analysis is conducted to identify the relationship between attributes such as papers and keywords [44]. There are many network analysis tools such as Gephi, VOSviewer, and Pajek [45]. This study uses the Gephi network analysis tool because of its ability to handle different data formats; it has powerful filtering techniques [45] and can manipulate large datasets [44] in addition to its ability to develop visual illustrations [46] for large networks which hastens the exploration

work [46]. Then, a clustering technique is conducted to identify and classify the sub-fields of our research topic [44,46], and the papers on similar topics are identified.

Using the network analysis, the following steps are performed: RFPN analysis.

Here, the relationship between the articles are analysed by delineating the common keywords between these articles. Next, the information is presented as a network visualization using Gephi.

Consider a weighted, undirected, and symmetric network N formed using S , the set of papers ($S = 1, \dots, i, \dots, j, \dots, m$), and K the set of keywords ($K = 1, \dots, p, \dots, q, \dots, n$) represented by a graph $G = (V, E)$, where V is the set of nodes and E the set of edges, respectively [46]. We present this network as a co-occurrence matrix with its rows and columns representing the nodes and its elements being the frequency of co-occurrence between each pair of nodes [47].

The network consists of nodes and edges. Each node represents an article i or j , and the edge represents at least one keyword which is shared between two articles. The edge weight between two nodes is equal to the number of co-occurring keywords between the two articles. The co-occurrence matrix A of size $m \times m$ and element a_{ij} can be written as:

$$a_{ij} = \sum_{k=1}^n g_{ijk} \quad (1)$$

if there is an edge from a paper i to j ; 0, otherwise, where

$$\sum_{k=1}^n g_{ijk} \quad (2)$$

represents the frequency of co-occurring keywords between nodes i and j and g_{ijk} takes a value of 1 if keyword k is listed in papers i and j , and g_{ijk} takes a value 0 otherwise [46].

This study constructs these relationships through two steps. First, we perform a co-occurrence matrix using Bibexcel and then import the .csv file into Gephi to create a network visualization for RFPN analysis. Second, we perform modularity computation to identify the subfields of the research domain and cluster them. This research used Force Atlas 2 to determine the layout of clusters and to determine which papers have common themes. Besides, modularity analysis helps researchers to identify the number of clusters.

Keyword occurrence analysis determines the appearance of pairs of keywords over a consecutive number of bibliographic records. If two keywords occur simultaneously in an article, then both articles have a semantic relationship [46]. Such an analysis helps to identify the research themes and areas of focus [43], and to obtain the relationship between the articles [46].

This study performs keyword co-occurrence analysis for each cluster separately and then presents the analysis by network visualization using Gephi. The KCON analysis portrays the relationships among the papers through their keywords. The core keyword of the cluster is positioned at the centre of the network and the strength of its link to other keywords is revealed through the arrows connecting the keywords to each other. Consider a network N represented by a co-occurrence matrix with its rows and columns representing the nodes and its elements recording the frequency of co-occurrence between each pair of nodes [46].

A network consists of nodes and edges. Each node denotes a keyword p or q . An edge indicates that the two linked keywords are listed in the same paper and the edge weight between two nodes represents the number of papers that list both keywords. Its co-occurrence matrix B of size $n \times n$ and element b_{pq} can be represented as follows:

$$B_{pq} = \sum_{s=1}^m h_{pqs} \quad (3)$$

if there is an edge from paper p to q ; 0, otherwise where

$$\sum_{s=1}^m h_{pqs} \quad (4)$$

represents the frequency of papers listing both keywords p and q and h_{pqs} takes a value of 1 if paper i lists both keywords p and q ; and takes a value 0 otherwise [46].

3. Results and Discussions

3.1. Keyword Retrieval and Standardization

Using BibExcel, 671 keywords are retrieved from 141 references. However, these keywords need to be standardized as many keywords are describing the same meaning. First, the plural keywords were converted to their singular form [46]. Next, similar keywords such as “Cross Dock,” “Cross-Dock,” and “Cross-Docking” were standardized to “Cross-Docking,” chosen based on the popularity of usage. Finally, the keywords that describe the same field or specialised area were standardized to a keyword of general usage; for example, terms such as “logistics,” “logistics approach,” “reverse logistics,” and “logistics systems” were standardized to “logistics”.

After standardization, the 671 keywords reduced to 54 unique keywords. Table 2 shows the top 20 most frequently occurring keywords.

Table 2. Top 20 keywords.

Keyword	Frequency
Cross-Docking	110
Scheduling	55
Logistics	49
Distribution	43
Linear and Integer Programming	36
Vehicle Routing	32
Supply Chain Management	29
Docking	17
Heuristic	17
Hybrid Metaheuristics	16
Genetic Algorithm	13
Transportation	13
Tabu Search	12
Performance Management	12
Inventory Management	11
Simulated Annealing	10
Networks Planning	9
Location	9
Production	8
Warehousing	8

As cross-docking seeks to reduce time and shipment cost by reducing inventory holding [1], it is associated with other vital logistics aspects such as scheduling, warehousing, and distribution. Scheduling is significant to cross-docking as the proper scheduling of the inbound and outbound trucks, outdoor and indoor assignments, and routing of delivery vehicles means more efficient cross-docking operations, which further reduces the costs of inventory holding and transportation. Efficiency in cross-docking operations can also positively impact on distribution operations by expediting distribution, minimizing transit times, and thus reducing the distribution costs and increasing customer satisfaction [39].

3.2. Journal Analysis

The 141 articles considered in our analysis were published in 51 subject journals. Figure 2 shows the distribution of papers by journal for the top 10 most published journals. More than half of the 141 papers are published in the top 20 journals.

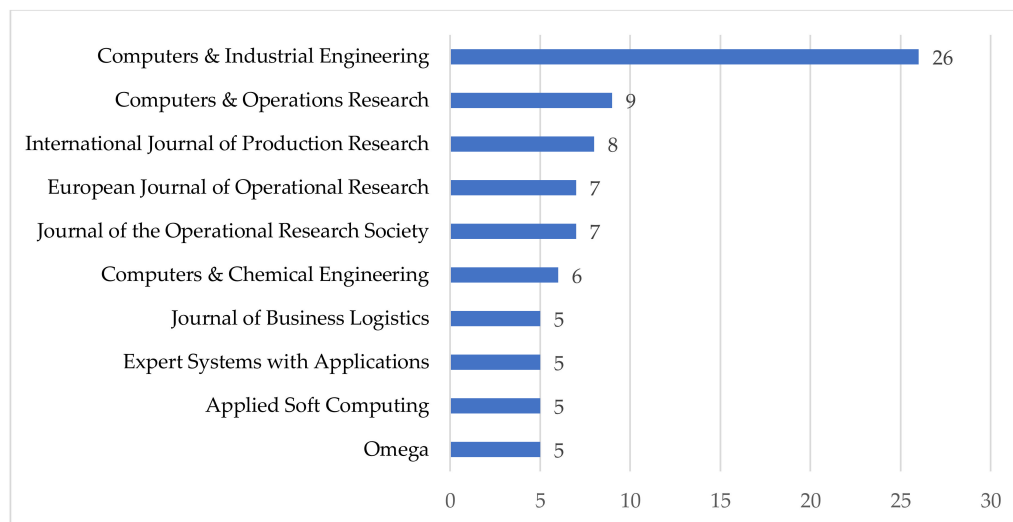


Figure 2. Distribution of papers by journal.

Computers and Industrial Engineering (CAIE) is a quality academic journal with an H index of 111 (Q1) using the SCImago journal rank indicator. CAIE publishes articles in industrial engineering. Scholars publish cross-docking papers with CAIE because it encourages authors to contribute to problem-solving methodologies, models, and related concepts [48]. Computers & Operations Research (COR) is another high-quality academic journal with an H index of 133, which encourages scholars to contribute to methods for determining the viable solutions to problems using techniques in computing and operations research on areas such as logistics and transportation. Researchers publish cross-docking articles in COR because the optimization problems related to cross-docking are a part of operations research [49].

3.3. Year Analysis

The 141 articles considered in our analysis are distributed throughout the past two decades between June 1997 and October 2018. Nearly 2/3 of the papers appear in the past 6 years. Table S1 shows the publication frequency.

3.4. Contributing Country Analysis

The contributing countries have been analysed to determine which countries have made the most contribution to this research area.

The countries are extracted from the author affiliations. Each author is considered separately as well as by country. Some authors have more than one country affiliation in the same paper. This study considers each country as a contribution even if they were for one author from one paper. Moreover, different countries for different authors from one paper are taken into consideration and each one is considered as a contributing country. The total number of unique contributing countries is 40. Table S2 shows the number of papers published annually by the top 10 contributing countries. Clearly, MIT in the US is the world leader in the engineering and technology subject area (www.topuniversities.com). Also, many Iranian scholars are very interested in performing mathematical analysis of real-world problems and have strong capabilities in delivering research related to a variety of engineering topics (www.usnews.com). Cross-docking needs extensive mathematical modelling and programming for

scheduling, vehicle routing, and network optimization. Hence, it is an interesting research area for them.

3.5. RFPN Analysis

This study performs the RFPN analysis in two steps. First, we construct the co-occurrence matrix using BibExcel. Next, we create the network visualization for the RFPN by importing the .csv file into Gephi. After importing the .csv file into Gephi, a network of 141 nodes and 8,059 edges was created. Figure S1a–c represent the raw network with 141 nodes, the Force Atlas 2 layout with no outliers, and the final network.

The RFPN visualization is shown in Figure S2 and shows the paper ID (see Supplementary Materials S1: List of Reviewed Papers to identify the paper ID). The node sizes are proportional to their eigenvector centrality score ranging from 0 to 1. A paper with an eigenvector centrality value of 1 is the most connected node in the network [46].

3.6. RFPN Clustering

This section identifies the sub-fields of the research domain by computing the modularity and then forming the RFPN network into 4 clusters as shown in Figure S3. Cluster 1 comprises 47 papers, while clusters 2, 3, and 4 have 40, 25, and 29, respectively, indicating that scholars pay attention to the research areas of these clusters. The eigenvector is calculated in order to specify the lead nodes in each cluster [46]. Table S3 shows the top 10 articles in each cluster based on the eigenvector centrality.

The articles with higher eigenvector centrality have greater influence in the cluster and represent the core research area. In general, the results show a strong association between the articles in all the clusters especially in Cluster 2 because its articles share a higher eigenvector centrality compared to the articles in the other clusters which means that the articles in Cluster 2 have a strong association with the other clusters.

3.7. Keyword Co-Occurrence Analysis

The keyword co-occurrence analysis was constructed using BibExcel for the keywords from each cluster separately. A generated .net file format was then imported into Gephi to obtain the keyword co-occurrence network for each cluster separately as shown in Figures 3–6 respectively. The Force Atlas 2 layout algorithm has been used to position the keywords that are linked in close proximity. The eigenvector centrality was measured to identify the core keywords in each cluster. Table 3 represents the top 20 keywords based on the eigenvector centrality in each cluster and helps to identify the keywords for a particular research area. Put simply, the major research themes in each cluster were identified from the influential keywords in each cluster. Consequently, the results retrieved 45, 35, 25, and 26 keywords from Clusters 1, 2, 3, and 4 respectively.

A higher eigenvector centrality for a keyword, represented by a node, indicates that this keyword has many neighbours or important neighbours [46]. From Table 3, five keywords (Cross-Docking, Vehicle Routing, Linear and Integer Programming, Simulated Annealing, and Performance Management) are found in all four clusters with high eigenvector centrality, indicating a strong association between these clusters. Moreover, there are 5 keywords (Scheduling, Heuristic, Tabu Search, Docking, and Variable Neighbourhood Search) found only in Clusters 1, 2, and 4; two keywords (Supply Chain Management and Transportation) are found in Clusters 1, 3, and 4; and two keywords (Production and Distribution) are found in Clusters 2, 3, and 4. Further, there are three keywords (Location, Stochastic Programming, and Warehousing) common to Clusters 1 and 4, three keywords (Logistics, Graph Theory, and Mathematical Models) found in Clusters 2 and 3, two keywords (Genetic Algorithm and Inventory Management) found in Clusters 1 and 3, one keyword (Hybrid Metaheuristics) in Clusters 1 and 2, and one keyword (Manufacturing) in clusters 3 and 4.

Those keywords appearing in more than one cluster are termed as bridging keywords. They highlight the relationship between the clusters. The more common the keywords between two clusters,

the greater is the association between them [46]. Clearly, the association between all 4 clusters is strong as they are connected through five bridging keywords.

It is worth noting that the cross-docking bridge keyword has a high eigenvector centrality in all clusters indicating its importance in all of the 4 clusters. Vehicle routing is critical in supporting cross-docking execution which includes warehouse management and distribution management [50] and helps in reducing operating costs.

Therefore, many studies integrate both cross-docking and distribution strategies in order to extend the integrated optimal solution such as minimizing the transportation costs and increasing the efficiency of deliveries and pickups [51]. Scholars have solved vehicle routing problems by applying various models and techniques such as Tabu search (TS) [30], iterated local search heuristics (ILS) [52], mixed-integer programming [39,53], simulated annealing (HAS) [51], and hybrid fuzzy possibilistic-stochastic programming [54]. Integer linear programming models are also considered in cross-docking studies because these models help to solve many related problems such as reducing transportation costs, increasing shipment rates, improving product management, designing the supply chain network, and providing scheduling and routing solutions [55]. Simulated annealing is a widely used meta-heuristic applied to cross-docking to tackle the combinatorial nature of cross-docking including location, assignment, and movement scheduling [56]. Performance management is also related to cross-docking as improving performance increases satisfaction, loyalty, and market opportunities [57].

Thus, we identified each cluster's research theme through the eigenvector centrality of the keywords for each cluster. Cluster 1 is Vehicle Routing/Inventory Management, Cluster 2 is Scheduling, Cluster 3 is Logistics, and Cluster 4 is Warehousing and Distribution respectively.

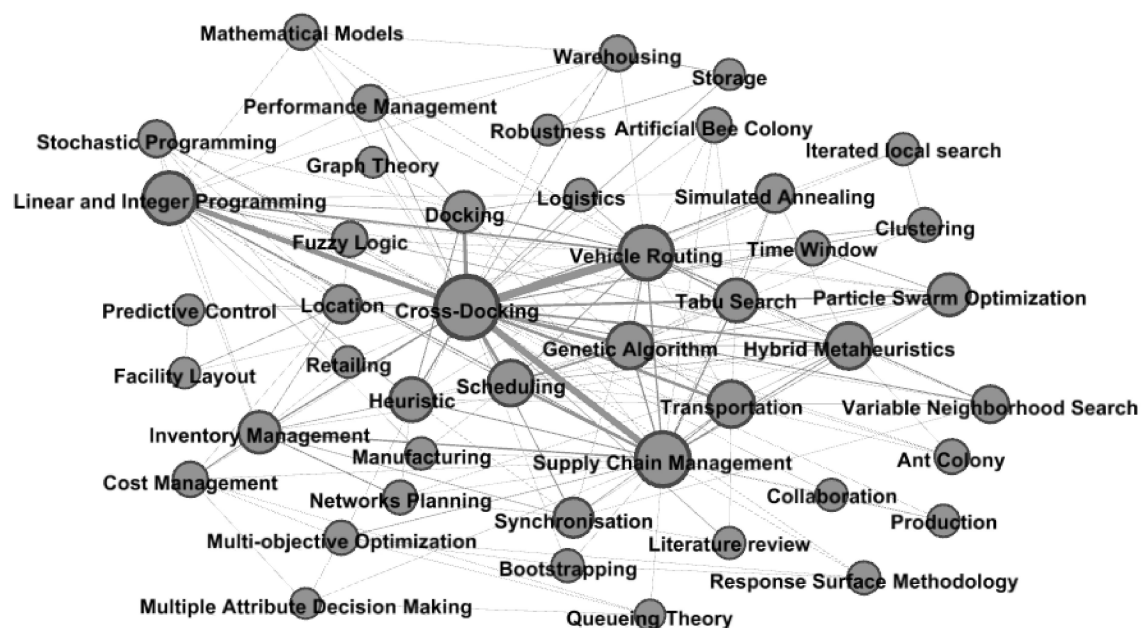


Figure 3. Keyword co-occurrence analysis of Cluster 1: Vehicle Routing/Inventory Management.

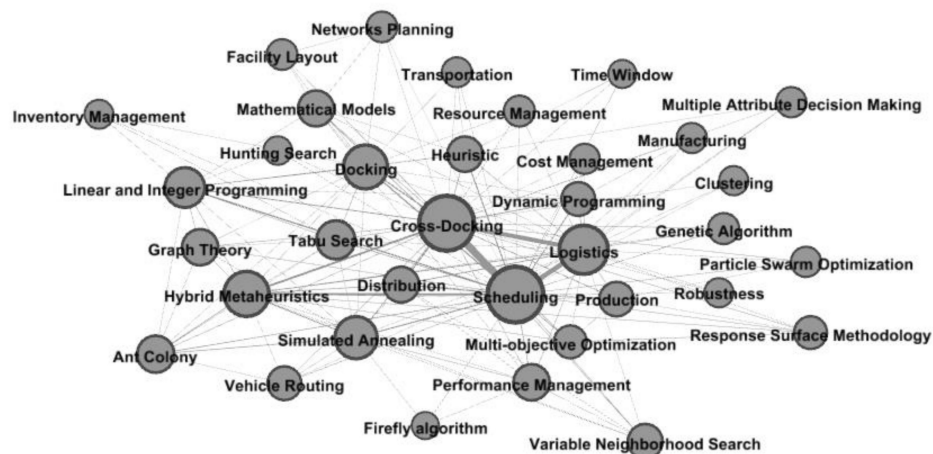


Figure 4. Keyword co-occurrence analysis of Cluster 2: Scheduling.

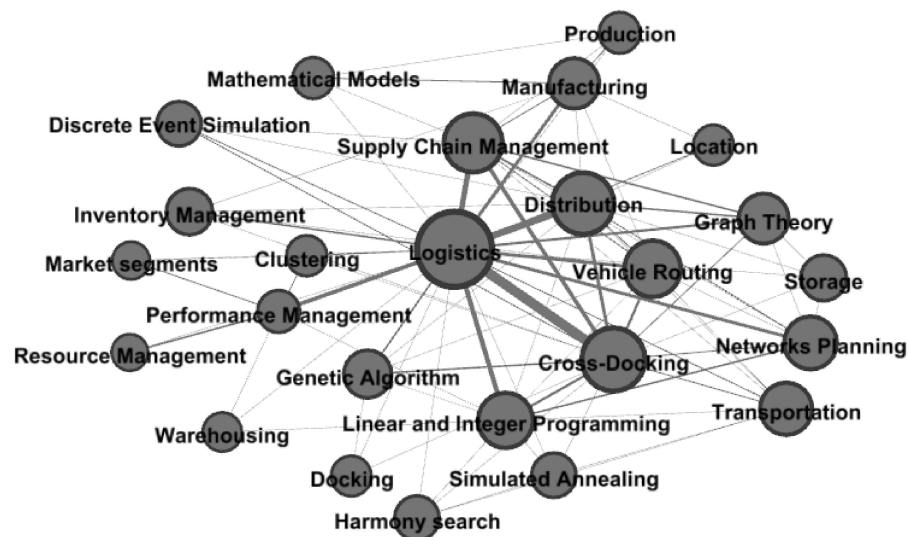


Figure 5. Keyword co-occurrence analysis of Cluster 3: Logistics.

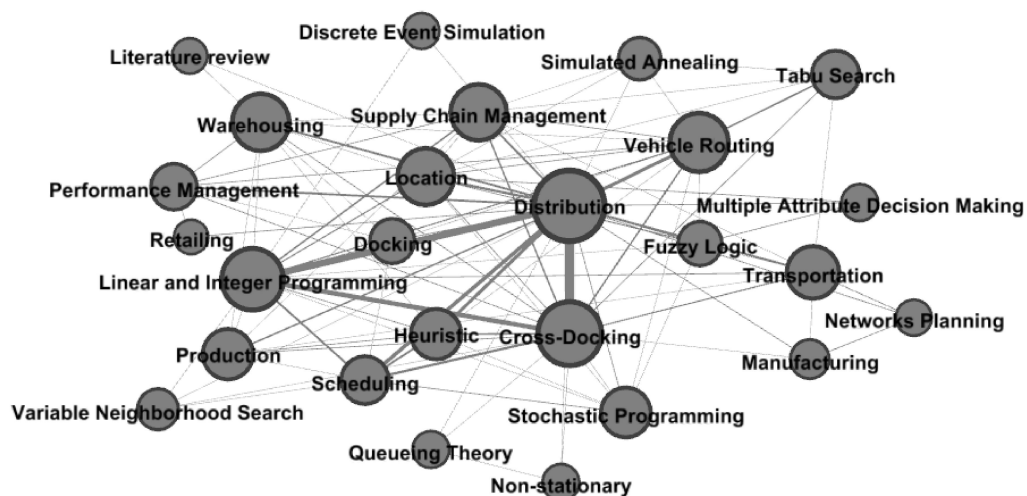


Figure 6. Keyword co-occurrence analysis of Cluster 4: Warehousing and Distribution.

Table 3. Top 20 keywords based on eigenvector centrality in each cluster.

Rank	Cluster 1: Vehicle Routing/Inventory Management		Cluster 2: Scheduling		Cluster 3: Logistics		Cluster 4: Warehousing and Distribution	
	Keywords	EVC*	Keywords	EVC	Keywords	EVC	Keywords	EVC
1	Cross-Docking	1	Scheduling	1	Logistics	1	Distribution	1
2	Supply Chain Management	0.76299	Cross-Docking	0.9729	Cross-Docking	0.734327	Cross-Docking	0.833576
3	Vehicle Routing	0.743678	Logistics	0.788799	Distribution	0.69745	Linear and Integer Programming	0.782785
4	Linear and Integer Programming	0.699076	Hybrid Metaheuristics	0.682326	Supply Chain Management	0.630789	Vehicle Routing	0.713216
5	Transportation	0.540495	Docking	0.649973	Vehicle Routing	0.578903	Warehousing	0.67861
6	Hybrid Metaheuristics	0.538099	Simulated Annealing	0.600426	Linear and Integer Programming	0.548282	Location	0.665832
7	Genetic Algorithm	0.534187	Linear and Integer Programming	0.532457	Networks Planning	0.498123	Supply Chain Management	0.654276
8	Scheduling	0.51701	Tabu Search	0.491198	Transportation	0.483642	Transportation	0.565639
9	Heuristic	0.467514	Ant Colony	0.443876	Manufacturing	0.441717	Production	0.516442
10	Tabu Search	0.446385	Performance Management	0.422078	Graph Theory	0.43476	Heuristic	0.516039
11	Particle Swarm Optimization	0.42075	Graph Theory	0.418574	Genetic Algorithm	0.379535	Stochastic Programming	0.502261
12	Inventory Management	0.412083	Mathematical Models	0.413196	Inventory Management	0.347127	Scheduling	0.454689
13	Docking	0.39131	Distribution	0.407254	Storage	0.337752	Tabu Search	0.4485
14	Synchronisation	0.347521	Heuristic	0.39393	Harmony search	0.310071	Performance Management	0.414748
15	Location	0.319009	Variable Neighbourhood Search	0.380262	Simulated Annealing	0.310071	Docking	0.381244
16	Simulated Annealing	0.318885	Production	0.370989	Discrete Event Simulation	0.307689	Fuzzy Logic	0.363862
17	Variable Neighbourhood Search	0.28169	Vehicle Routing	0.350027	Performance Management	0.256504	Simulated Annealing	0.327904
18	Stochastic Programming	0.271833	Dynamic Programming	0.346912	Mathematical Models	0.233168	Variable Neighbourhood Search	0.289903
19	Performance Management	0.253003	Multi-objective Optimization	0.323562	Production	0.233168	Manufacturing	0.243781
20	Warehousing	0.242288	Response Surface Methodology	0.323562	Clustering	0.218689	Non-stationary	0.192331

* EVC—Eigenvector centrality.

3.8. Discussion

Cross-docking is a valuable supply chain strategy given that it offers several benefits, for example, reduction in inventory holding costs, reduction in transportation costs, and on-time deliveries [58–60]. By looking at the end-to-end supply chain process, cross-docking involves product flow from the manufacturing plant directly to the customers with minimal or no warehousing in-between. In addition, implementing cross-docking is aligned to the lean thinking approach, which leads to cost reduction. For instance, implementing retail cross-docking at supermarkets that deliver multiple orders from suppliers utilizes less workforce due to the products no longer requiring picking and putting away in the supermarket's warehouse facility.

3.8.1. Techniques Used for Cross-Docking Optimization

All the clusters include techniques and models on optimization and simulation. Mathematical optimization is used to help in making complex decisions and finding optimal solutions such as minimizing traffic during loading/unloading dock scheduling, improving cross-docking assignment [61], and selecting best product sizes for cross-docking [62].

Simulation is used to mimic real-world operations [61], such as developing an event simulator to evaluate package flows and sortation times under various cross-docking output station assignments [61] and simulating various warehouse floor area configurations related to optimal cross-dock capacity and movement efficiency [63]. The simulation models that have been applied include the more traditional approaches of hybrid metaheuristics, genetic algorithm, Tabu search, particle swarm optimization, simulated annealing, and variable neighbourhood search. For instance, hybrid metaheuristics, combining genetic algorithm, and modified variable neighbourhood search are well-used for vehicle routing in cross-docking. Simulated annealing with Tabu search is used in network design and in location planning for cross-docking and flow centre design. A hybrid of genetic algorithm and particle swarm optimization is used to minimize the transportation and fixed costs of multiple cross-docked vehicle routing with pickup, delivery, and time windows. The more frequently applied optimization techniques used in this cluster are linear and integer programming. Our review results suggest that there is a lack of multi-attribute decision making techniques used in cross-docking, and newer simulation approaches such as agent-based modelling.

So far, our findings identify that both optimization and simulation are used extensively in cross-docking. Scheduling (Cluster 2) has adopted the use of optimization and simulation more than the other clusters (5 for simulation and 6 for optimization) followed by vehicle routing/inventory management (Cluster 1) (6 for simulation and 3 for optimization). Both logistics (cluster 3) and warehousing and distribution (Cluster 4) adopted 6 techniques (4 for simulation and 2 for optimization, and 3 each for simulation and optimization, respectively). For vehicle routing/inventory management (Cluster 1) and logistics (Cluster 3), simulation is twice more likely to be used for the optimization. This outcome is attributed to the non-polynomial nature of the problem at hand. While in the areas of scheduling (Cluster 2) and warehousing and distribution (Cluster 4), scholars have used both techniques almost equally.

Based on the eigenvector values, linear and integer programming is the most prevalent technique used in the optimization suite to solve vehicle routing/inventory management (Cluster 1), logistics (Cluster 3), and warehousing and distribution (Cluster 4). Integer linear programming models are applied in cross-docking because of their efficiency in providing optimal solutions [55], such as minimizing vehicle and transportation costs [51], scheduling truck fleets [64], and optimizing internal operations in a less-than-truckload cross-dock [65]. In the domain of scheduling (cluster 2), hybrid metaheuristics is the most important technique.

Hybrid metaheuristics is also the second important approach applied to vehicle routing/inventory management (Cluster 1). Metaheuristics models are used to provide good solutions, such as finding the best vehicle routing in a short time [66] and providing vehicle routing under stochastic demand [67]. Simulated annealing is the second most commonly applied technique in scheduling (Cluster 2), due to

its efficacy in solving combinatorial problems such as truck scheduling in multiple door cross-docking systems and truck scheduling for fixed outbound schedules [56]. In logistics (Cluster 3), the second most commonly used technique is graph theory, which helps to visualize systems as graphs to facilitate decision making [68]. In warehousing and distribution (Cluster 4), heuristics are the second commonly used technique for problems, such as scheduling cross-dock operations [65].

3.8.2. Implications of Research in each Cluster

Inventory cost is one of the three most significant cost centres for supply chain management. Cross-docking is a remedy to reduce the total cost of ownership by minimizing the inventory cost without compromising the responsiveness of the supply chain. Firms are constantly striving to develop efficient approaches to optimize the operations of cross-docks and minimize the total cost of the system. Firms also try to optimize the scheduling of the inbound and outbound vehicles by minimizing the idle time or empty travels of the vehicles. Given a large number of decision variables in scheduling, vehicle routing, and inventory management for cross-docking operations, non-linear optimization models are more suitable to handle them. Therefore, optimization techniques using metaheuristics and simulation are commonly used for this purpose. Inventory management, vehicle routing, and scheduling are highly interrelated cost centres as they are directly related to logistics and warehousing. In other words, all these operations must be integrated through a highly efficient decision support system (DSS). Such a DSS ensures that the operations of the cross-dock are performed seamlessly to satisfy the requirements of the set of the supply chain partners. Cross-docking is a relatively new concept in logistics and warehousing; however, it has provided organizations with many advantages such as lower demand for inventory investment and storage space, speeding the deliveries, and improving inventory turnover.

In the past five years, more than 40% of the food and beverage industry logistics executives surveyed have increased their cross-docking practices. This increase is due to the businesses seeking new approaches to fulfil demand and the need for just-in-time services. Besides, businesses would like to improve service to customers [69]. For example, through cross-docking, perishable products including food and beverages reach the marketplace quicker, fresher, and with preserved quality. For instance, the large grocery chains can now keep fresher products on their shelves consistently.

The main role of cross-docking in this practice is related to logistics and transportation. Other characteristics for cross-docking practices are shipping patterns and high-volume products with a short time window. Also, cross-docking practices can work best for multiple stock-keeping units (SKUs) that are consistently shipped to multiple locations. Some store chains like grocery chains, bring the products into one location and re-split them to multiple locations at different stores. A study of cross-docking in the retail sector [70] examined the costs/benefits of implementing the cross-docking strategy in a major French retail supply chain, in particular, fast-moving consumer goods.

Previous studies show that the ingredient factors for logistics and distribution companies to implement supply chain and logistics are collaboration with other supply chain trading partners or logistics service providers, effective communication, and synchronization of inbound and outbound shipments. Moreover, the Logistics Bureau has suggested six useful factors to practise cross-docking in logistics and distribution strategies [71], i.e.,

- use conveyors if possible,
- housekeeping needs to be up-to-date,
- use dock space sparingly,
- locations require adequate yard space,
- shipment-staging area needs to be well-organized,
- technology-based solutions are useful.

Warehouse Management Systems (WMS) are designed to facilitate cross-docking operations and to address issues related to inventory and data visibility, traceability, supply chain agility, and operational

adaptability. To implement WMS for a cross-docking facility, Automated Data Collection (ADC) integration is required to capture data in real-time to reduce manual data entry and errors while improving data accuracy within the facility.

3.9. Future Research Directions

Looking at the existing research in cross-docking, the following avenues are recommended to future researchers.

- Uncertainties in demand and supply reduce the efficiency of statically optimized operations. In a global supply chain, a fair amount of stochasticity and variability in time exist, the supply chain stakeholders need to adapt to those perturbations. Research can study the dynamic optimization of cross-docking operations when the supply and demand fluctuate with time.
- Since cross-docking seeks to improve customer satisfaction by providing better services at a relatively lower cost, future research can be devoted to evaluating the relationships among customer satisfaction, operational efficiency of the firm, and the operational efficiency of the cross-docking centres.
- Transportation is one of the top three industries significantly contributing to environmental pollution. Future studies can develop multi-objective optimization models to minimize environmental pollution along with the traditional objectives such as minimizing delivery time, location, and resource allocation decisions.
- Corporate social responsibility is a major concern for firms. Planning seaports and dry ports in crowded and congested areas needs cross-docking transportation and delivery services to address the social welfare of residents in those urban areas. Future studies can analyse the cost-benefit trade-offs of establishing cross-docks in urban areas and examine the vehicle routing optimization for cross-docks under social sustainability and corporate social responsibility.
- To enhance cross-docking operations and to be a smart and intelligent logistics system, the adapted concepts and design solutions should be developed to provide systematic management of the smart operation in cross-docking which are synchronized with other cross-docking problems. Future research may focus on developing smarter and more advanced technologies to support cross-docking.
- Since the internal operations between the inbound and the outbound dock-doors of cross-docking have not attracted more attention, future research on cross-docking can focus on the task scheduling inside the cross-docking terminals considering resource capacity and constraints.
- Given the supply chain risks and uncertainties (for instance, COVID-19; uncertainties in demand and supply), future research of cross-docking operations can examine the sources of uncertainty (identification and discussion of the risks and uncertainties) to develop distributionally robust optimization models which can improve the practicality, accuracy, and efficiency of the cross-docking operations.
- From the logistics, warehouse, and distribution performance point of view, there are several recommendations to improve their operations through cross-docking practices; for example, developing a suitable WMS for cross-docking operations, and the continuous improvement of suppliers through strategic supplier partnerships with higher transparency.

4. Implications and Conclusions

This study reviewed the research on cross-docking between 1997 and 2018. BibExcel and the Gephi network analysis tool were used as the bibliometric analysis tools to visualize the interrelations among the papers and their characteristics such as keywords, authors, country of authors, and year of publication. We identified four streams of research in cross-docking: vehicle routing/inventory management, scheduling, logistics, warehousing, and distribution.

Policy implications relate to the way in which policies may improve various elements of cross-docking, including scheduling, warehousing, and logistics operations, and support the improved distribution of goods. The implementation of an adaptive policy instead of a fixed stock policy, in line with the findings of Khorasani et al. [19], is better placed to allow for cost savings in cross-docking situations. Inventory ordering policy, a key opportunity to gain efficiencies in cross-docking [72], suggest that replenishment policies are key to gaining time and cost improvements with cross-docking. Buijs et al. (2016) propose that dynamic allocation policies for assigning trucks to cross-docking doors is an important policy for gaining cross-docking advantage. Policies that offer flexible and agile solutions appear to have greater fit with cross-docking [60].

Reviewing the techniques used for cross-docking operations showed that linear and integer programming, non-linear programming, and stochastic programming are the most frequently used optimization approaches for cross-docking. Several meta-heuristics such as particle swarm optimization, tabu search, simulated annealing, and genetic algorithm have been applied to simulate cross-docking operations. From the systematic literature review on cross-docking, we have offered several directions for future research. Although we reviewed many papers to perform the analysis, a limitation of this research is that we did not include the book chapters and conference papers. Future studies can be devoted to determining the main research streams through reviewing this set of publications. Furthermore, we only worked on papers that have been published in English. Future researchers can review the relevant documents published in the other languages.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2071-1050/12/11/4789/s1>: Figure S1: Stages in RFPN analysis visualization using Gephi, Figure S2: RFPN visualization, Figure S3: Clustered RFPN with node size proportional to eigenvector centrality, Table S1: Publication frequency, Table S2: Number of papers published for the top 10 countries by year, Table S3: Top 10 articles in RFPN clusters based on eigenvector centrality, Supplementary Materials S1: List of papers reviewed with the relevant ID.

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